Stable FSK Modems Featuring the XR-2207, XR-2206 and XR-2211

INTRODUCTION

Frequency-shift keying (FSK) is the most commonly used method for transmitting digital data over telecommunications links. In order to use FSK, a modulator/demodulator (modem) is needed to translate digital 1's and 0's into their respective frequencies and back again. This application note describes the design of a modem using state-of-the-art Exar devices specifically intended for modem application.

The devices featured in this application note are the XR-2206 and XR-2207 FSK Modulators, and the XR-2211 FSK demodulator with carrier-detect capability. Because of the superior frequency stability of these devices (typically 20 ppm/°C), a properly designed modem will be virtually free of the temperature and voltage-dependent drift problems associated with many other designs. In addition, the demodulator performance is independent of incoming signal strength variation over a 60 dB dynamic range. Because bias voltages are generated internally, the external parts count is much lower than in most other designs. The modem designs shown in this application note can be used with mark and space frequencies, anywhere from several Hz to 100 kHz.

PRINCIPLES OF OPERATION

The XR-2206 FSK Modulator

FEATURES

Typically 20 ppm/°C Temperature Stability
Choice of 0.5% THD Sine Wave, Triangle, or Square Wave Output
Phase-Continuous FSK Output
Inputs are TTL and CMOS Compatible
Low-Power Supply Sensitivity (0.01%

Low-Power Supply Sensitivity (0.01%/V)
Split or Single Supply Operation
Low External Parts Count

The XR-2206 is ideal for FSK applications requiring the spectral purity of a sinusoidal output waveform. It offers TTL and CMOS compatibility, excellent frequency stability, and ease of application. The XR-2206 can typically provide a 3-volt p-p sine wave output. Total harmonic distortion can be trimmed to 0.5%. If left untrimmed, it is approximately 2.5%.

The circuit connection for the XR-2206 FSK Generator is shown in Figure 1. The data input is applied to Pin 9. A high-level signal selects the frequency $(1/R_6C_3)$ Hz; a low level signal selects the frequency $(1/R_7C_3)$ Hz, (resistors in ohms and capacitors in farads). For optimum stability, R_6 and R_7 should be within the range of 10 kΩ to 100 kΩ. The voltage applied to Pin 9 should be selected to fall between ground and V+.

Note: Over and under voltage may damage the device.

Potentiometers, R_8 and R_9, should be adjusted for minimum total harmonic distortion. In applications where minimal distortion is unnecessary, Pins 15 and 16 may be left open-circuited and R_8 may be replaced by a fixed 200Ω resistor.

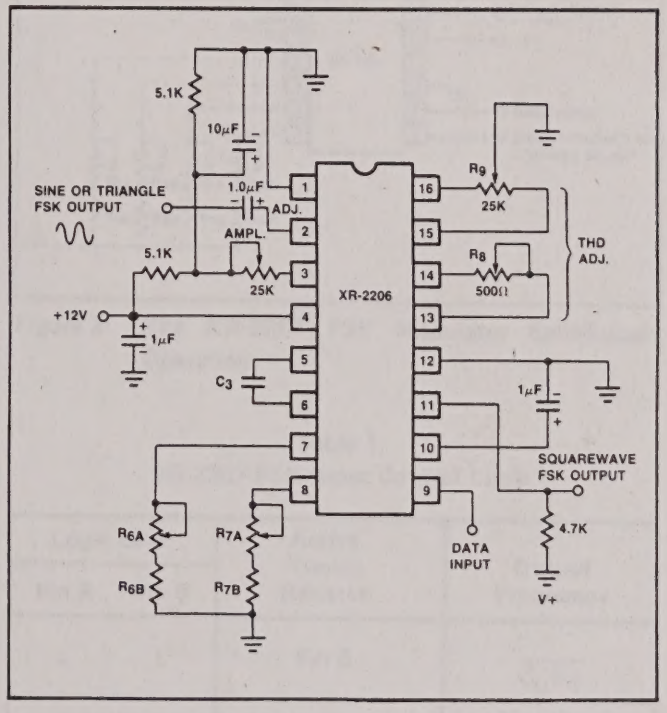


Figure 1: The XR-2206 Sinusoidal FSK Generator

In applications where a triangular output waveform is satisfactory, Pins 13 through 16 may be left open-circuited.

The output impedance at Pin 2 is about 600Ω, with ac coupling normally being used.

THE XR-2207 FSK MODULATOR

FEATURES

Typically 20 ppm/°C Temperature Stability
Phase-Continuous FSK Output
Provides Both Triangle and Square Wave Outputs
Operates Single-Channel or Two-Channel Multiplex
Inputs are TTL and CMOS Compatible
Split- or Single-Power Supply Operation
Low-Power Supply Sensitivity (0.15%/V)
Low External Parts Count

The XR-2207 is a stable FSK generator which is designed for those applications where only a triangle or square wave output is required. It is capable of either single-channel or two-channel multiplex operation, and can be used easily with either split- or single-power supplies.

Figure 2 shows the XR-2207 using a single-supply and Figure 3 shows split-supply operation. When used as an FSK modulator, Pin 8 and 9 provide the digital inputs. When the 2207 is used with a split-supply, the threshold at these pins is approximately +2 volts, which is a level that is compatible with both TTL and CMOS logic forms. When used with a single-supply, the threshold is near mid-supply and is CMOS compatible. Table 1 shows how to select the timing resistors, R_1 through R_4, to determine the output frequency based on the logic levels applied to Pin 8 and 9. For optimum stability, the values of R_1 and R_3 should be selected to fall between 10 kΩ and 100 kΩ.

With Pin 8 grounded, Pin 9 serves as the data input. A high-level signal applied to Pin 8 will disable the oscillator. When used in this manner, Pin 8 of the XR-2207 serves as the channel select input. For two-channel multiplex operation, Pin 4 and 5 should be connected as shown by the dotted lines. (For single channel operation, Pin 4 and 5 should be left open-circuited.)

The XR-2207 provides two outputs: a square wave at Pin 13 and a triangle wave at Pin 14. (For safe operation, current into Pin 13 should be limited to 20 mA.) When used with a split-supply, the triangle wave peak-to-peak amplitude is equal to V^- and the dc level is near ground. Direct coupling is usually used. With a single-supply, the peak-to-peak amplitude is approximately equal to one-half/V^+, the dc level is approximately at mid-supply, and ac coupling is usually necessary. In either case, the output impedance is typically 10Ω and is internally protected against short circuits.

The square wave output has an npn open-collector configuration. When connected as shown in Figure 2 or 3, this output voltage will swing between V^+ and the voltage at Pin 12.

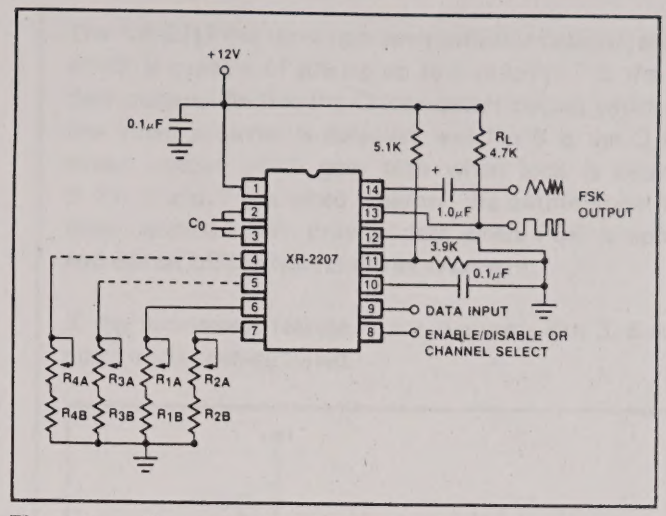


Figure 2: The XR-2207 FSK Modulator Single-Supply Operation

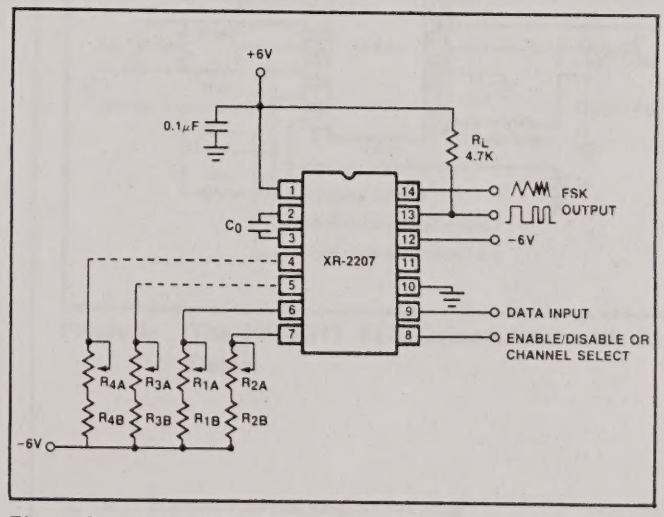
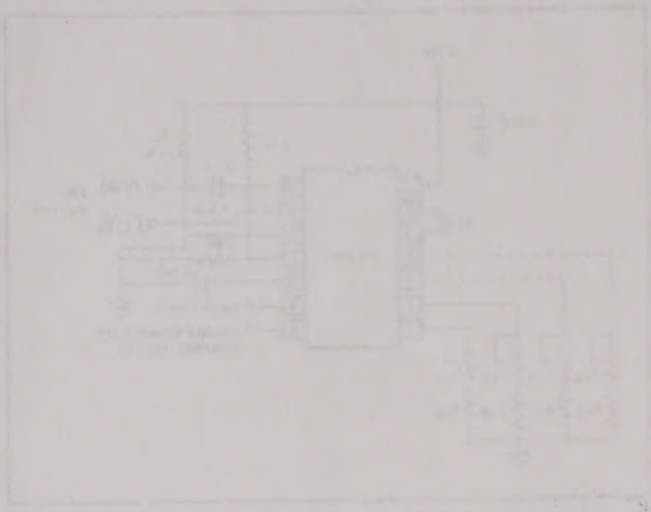


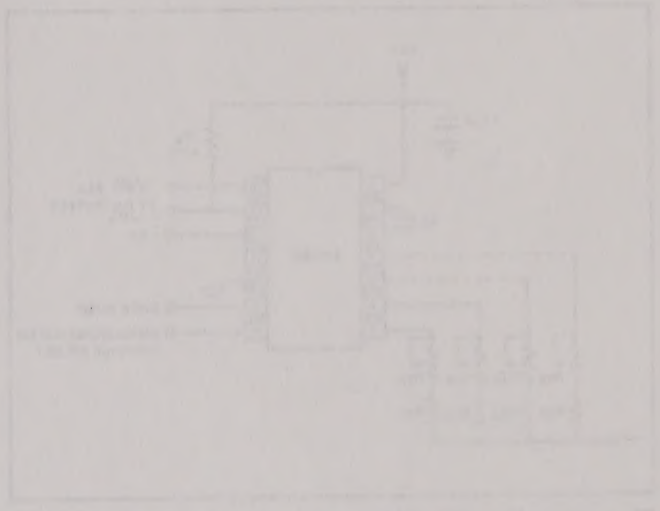
Figure 3: The XR-2207 FSK Modulator Split-Supply Operation

Table 1.
SR-2207 FSK Input Control Logic

Logic Level		Active Timing Resistor	Output Frequency
Pin 8	Pin 9		
L	L	Pin 6	$\frac{1}{C_0R_1}$
L	H	Pins 6 and 7	$\frac{1}{C_0R_1} + \frac{1}{C_0R_2}$
H	L	Pin 5	$\frac{1}{C_0R_3}$
H	H	Pins 4 and 5	$\frac{1}{C_0R_3} + \frac{1}{C_0R_4}$

Units: Resistors — Ohms; Capacitors — Farads; Frequency — Hz





THE XR-2211 FSK DEMODULATOR

FEATURES

Typically 20 ppm/°C Temperature Stability
Simultaneous FSK and Carrier-Detect Output
Outputs are TTL and CMOS Compatible
Wide Dynamic Range (2 mV to 3V rms)
Split or Single Supply Operation
Low-Power Supply Sensitivity (0.05%/V)
Low External Parts Count

The XR-2211 is an FSK demodulator which operates on the phase-locked loop principle. Its performance is virtually independent of input signal strength variations, over the range of 2 mV to 3V rms.

Figure 4 shows the circuit connection for the XR-2211. The center frequency is determined by $f_o = (1/C_1R_4)$ Hz, where capacitance is in farads and resistance is in ohms. Calculation for f_o should fall mid-way between the mark and space frequencies.

The tracking range ($\pm\Delta f$) is the range of frequencies over which the phase-locked loop can retain lock with a swept input signal. This range is determined by the formula: $\Delta f = (R_4 f_0/R_5)$ Hz. Δf should be made equal to, or slightly less than, the difference between the mark and space frequencies. For optimum stability, choose an R_4 between 10 kΩ and 100 kΩ.

The capture range ($\pm\Delta f_c$) is the range of frequencies over which the phase-locked loop can acquire lock. It is always less than the tracking range. The capture range is limited by C_2, which, in conjunction with R_5, forms the loop filter time constant. In most modem applications, Δf_c = (80%–99%) Δf.

The loop-damping factor (ζ) determines the amount of overshoot, undershoot, or ringing present in the phase-locked loop's response to a step change in frequency. It is determined by $\zeta = 1/4\sqrt{C_1/C_2}$. For most modem applications, choose $\zeta \approx 1/2$.

The FSK output filter time constant (τ_F) removes chatter from the FSK output. The formula is: $\tau_F = R_F C_F$. Normally calculate τ_F to be approximately equal to [0.3/(baud rate)] seconds.

The lock-detect filter capacitor (C_D) removes chatter from the lock-detect output. With R_D = 510 kΩ, the minimum value of C_D can be determined by: $C_D(\mu f) \approx 16$/capture range in Hz.

Note: Excessive values of C_D will unnecessarily slow the lock-detect response time.

The XR-2211 has three npn open-collector outputs, each of which is capable of sinking up to 5 mA. Pin 7 is the FSK data output, Pin 5 is the Q lock-detect output which goes low when a carrier is detected, and Pin 6 is the Q lock-detect output which goes high when lock is detected. If Pin 6 and 7 are wired together, the output signal from these terminals will provide data when FSK is applied, and will be LOW when no carrier is present.

If the lock-detect feature is not required, Pins 3, 5 and 6 may be left open-circuited.

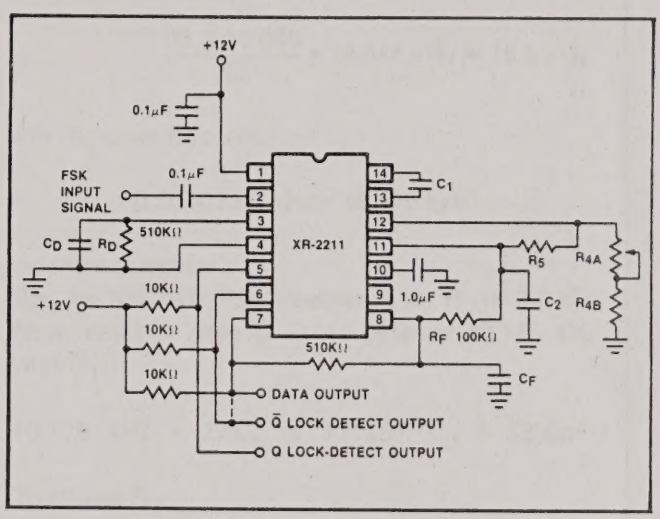
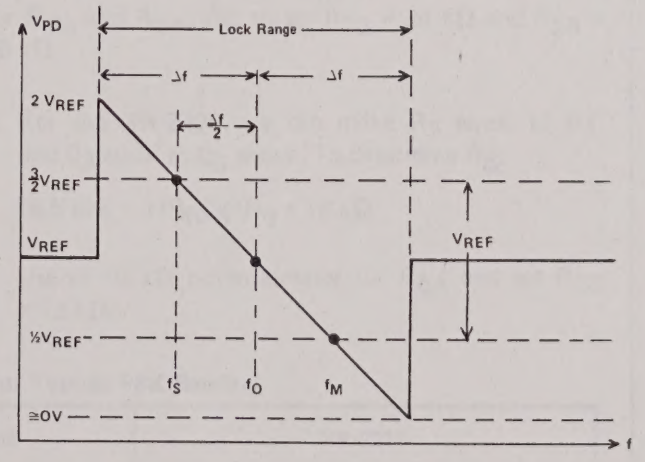
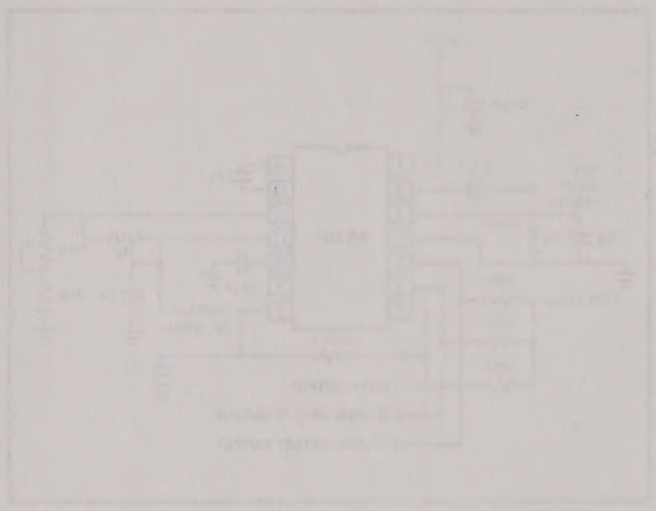


Figure 4: The XR-2211 FSK Demodulator with Carrier Detect



XR-2211 TRACKING CHARACTERISTICS

As seen above, the XR-2211 produces at its phase detector output a voltage V_{PD}, which has a peak to peak value equal to about V_{REF} for a frequency swing from f_M (mark) to f_S (space). The DC level of V_{PD} will be about V_{REF} $(\frac{V+}{2} - .65)$.



CIRCUIT DESIGN

Table 2 shows recommended component values for the three most commonly used FSK bands. In many instances, system constraints dictate the use of some non-standard FSK bands. The XR-2206/XR-2207/XR-2211 combination is suitable for any range of frequencies from several Hertz to 100 kiloHertz.

Here are several guidelines to use when calculating non-standard frequencies:

- For maximum baud rate, choose the highest upper frequency that is consistent with the system bandwidth.
- The lower frequency must be at least 55% of the upper frequency (less than a 2:1 ratio).
- For minimum demodulated output pulse-width jitter, select an FSK band whose mark and space frequencies are both high, compared to the baud rate. (i.e., for a 300 baud channel, mark and space frequencies of 2025 Hz and 2225 Hz would result in significantly less pulse-width jitter than 300 Hz and 550 Hz).
- For any given pair of mark and space frequencies, there is a limit to the baud rate that can be achieved. When maximum spacing between the mark and space frequencies is used (where the ratio is close to 2:1) the relationship

$$\frac{\text{mark-space frequency difference (Hz)}}{\text{maximum data rate (baud)}} \geq 83\%$$

should be observed.

For narrower spacing, the minimum ratio should be about 67%.

The values shown in Table 2 may be scaled proportionately for mark and space frequencies, maximum baud rate, and (inversely) capacitor value. It is best to retain (approximately) the resistor values shown.

DESIGN EXAMPLES

I. Design a modem to handle a 10 kilobaud data rate, using the minimum necessary bandwidth.

A. Frequency Calculation

Because we want to use the minimum possible bandwidth (lowest possible upper frequency) we will use a 55:100 frequency ratio. The frequency difference, or 45% of the upper frequency, will be 83% of 10,000. We therefore choose an upper frequency:

$$\frac{83 \times 10{,}000}{45} = 18.444 \text{ kHz} \approx 18.5 \text{ kHz}.$$

and the lower frequency:

$$0.55 \times 18.5 \text{ kHz} = 10.175 \text{ kHz}.$$

B. Component Selection

1. For the XR-2207 FSK modulator, set $R_1 \approx 30$ kΩ. Now, select a value of C_0 to generate 10.175 kHz with R_1:

$$10.175 \text{ kHz} = 1/(C_0 \times 30{,}000); \quad C_0 = 3300\text{pF}.$$

To choose R_2:

$$18.500 \text{ kHz} - 10.175 \text{ kHz} = 8.325 \text{ kHz} = 1/C_0R_2; \quad R_2 = 36 \text{ k}\Omega.$$

A good choice would be to use 10 kΩ potentiometers for R_{1A} and R_{2A}, and to set R_{1B} = 24 kΩ and R_{2B} = 30 kΩ.

2. For the XR-2206, we can make R_7 equal to R_1, and C_3 equal to C_0 above. To determine R_6:

$$18.5 \text{ kHz} = 1/R_6C_3; \quad R_6 = 16 \text{ k}\Omega$$

Use at 10 kΩ potentiometer for R_{6A} and set R_{6B} = 13 kΩ.

Table 2.
Recommended Component Values for Typical FSK Bands

FSK Band			XR-2207					XR-2206					XR-2211						
Baud Rate	f_L	f_H	R_{1A} R_{3A}	R_{1B} R_{3B}	R_{2A} R_{4A}	R_{2B} R_{4B}	C_0	R_{6A}	R_{6B}	R_{7A}	R_{7B}	C_3	R_{4A}	R_{4B}	R_5	C_1	C_2	C_F	C_D
300	1070	1270	10	20	100	100	.039	10	18	10	20	.039	10	18	100	.039	.01	.005	.05
300	2025	2225	10	18	150	160	.022	10	16	10	18	.022	10	18	200	.022	.0047	.005	.05
1200	1200	2200	20	30	20	36	.022	10	16	20	30	.022	10	18	30	.027	.0033	.0022	.01

Units: Frequency – Hz; Resistors – kΩ; Capacitors – μF

3. For the XR-2211 demodulator, we need to first determine R_4 and C_1. First, $f_o = (f_L + f_H)/2 = (10.175 + 18.500)/2 = 14.338$ kHz. If we make $R_4 = 25\ k\Omega$, then $1/(C_1 \times 25{,}000) = 14{,}338$; $C_1 = 2790\ pF \approx 2700\ pF$. With that value of C_1, the precise value of R_4 is now 25.8 kΩ. Select $R_{4B} = 18\ k\Omega$ and use a 10 kΩ for R_{4A}.

C. Frequency Component Selection

1. To calculate R_5, we first need our Δf, which is 18,500 – 10.175, or 8.325 kHz:

$$8325 = (25{,}800 \times 14{,}338)/R_5$$
$$R_5 = 44.4\ k\Omega \approx 47\ k\Omega.$$

2. To determine C_2 use $\zeta = 1/2 = 1/4 \quad C_1/C_2$. Then, $C_2 = 1/4C_1$; $C_2 = 670$ pF:

3. To select C_F, we use τ_F = [0.3/(baud rate)] seconds:

$$\tau_F = 0.3/10{,}000 = 30\ \mu sec.$$

with

$$R_F = 100\ k\Omega,\ C_F = 300\ pF$$

D. Lock Range Selection

To select C_D, let us start with the actual lock range:

$$\Delta f = R_4 f_o / R_5\ Hz = 7870\ Hz$$

If we assume a capture range of 80%:

$$\Delta f_C = 6296\ Hz$$

therefore, our total capture range of $\pm\Delta f_C$ is 12,592 Hz. Our minimum value for C_D is (16/12,592) μf or 0.0013 μf.

E. Completed Circuit Example

See Figure 5.

II. Design a 3 kilobaud modem to operate with low output jitter. The bandwidth available is 13 kHz.

For this modem, we can take the values from two for the 300 baud modem operating at 1070 Hz and 1270 Hz, multiply our baud rate and mark and space frequencies by ten, and divide all capacitor values on the table by ten. Resistor values should be left as they are.

III. Design a 2 channel multiplex FSK modulator to operate at the following pairs of mark and space frequencies: 600 Hz and 900 Hz, and 1400 and 1700 Hz (each of these channels could handle about 400 baud).

For this task, we will use the XR-2207. The only real consideration here is that, if possible, we want to keep the following resistances all between 10 kΩ and 100 kΩ: R_1, R_1/R_2, R_3 and R_3/R_4. The ratio between the maximum and minimum frequencies is less than 3:1, so we should have no trouble meeting this criterion. If we set our maximum frequency with an R of about 20 kΩ, we have: $1700 = 1/(C_o \times 20{,}000)$; $C_o = 0.029\ \mu f$ which is approximately equal to 0.033 μf.

Calculating R_1 using 600 Hz and 0.033 μf, we get R_1 = 50,5 kΩ. We can use $R_{1B} = 47\ k\Omega$ and $R_{1A} = 10\ k\Omega$. For R_2, we get 101 kΩ. Use $R_{2B} = 91\ k\Omega$ and $R_{2A} = 20\ k\Omega$. To determine R_3, use: $1400\ Hz = 1/R_3C_o$, which gives us $R_3 = 21.6\ k\Omega$. Use $R_{3B} = 18\ k\Omega$ and $R_{3A} = 5\ k\Omega$. R_4 must generate a 300 Hz shift in frequency, the same as R_2. Therefore, set R_4 equal to R_2.

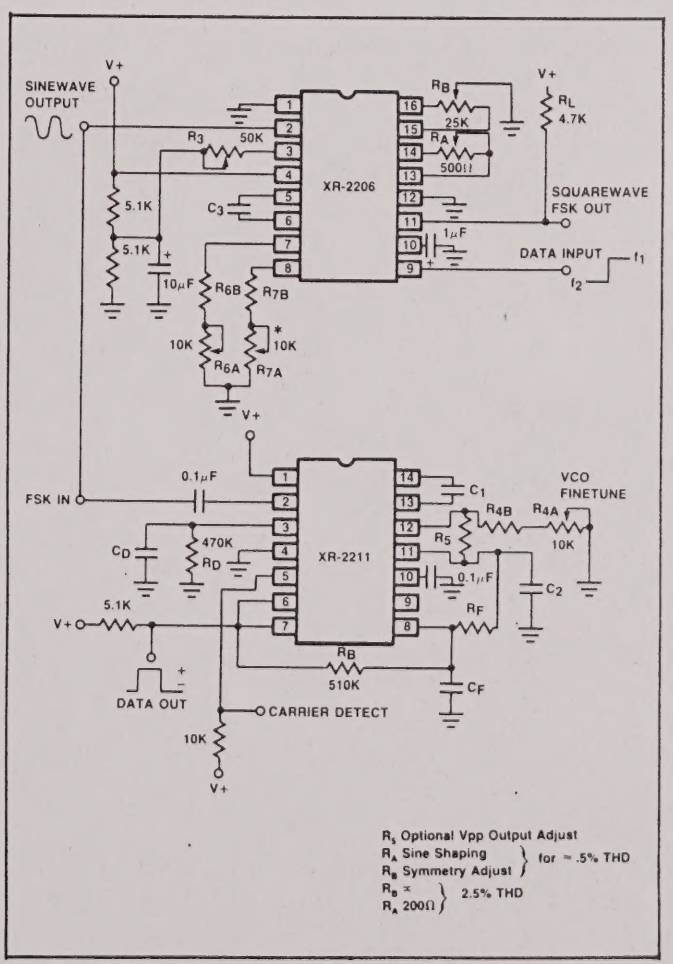


Figure 5: Full Duplex FSK Modem Using XR-2206 and XR-2211. (See Table 2 for Component Values.)

Adjustment Procedure

The only adjustments that are required with any of the circuits in this application note are those for frequency fine tuning. Although these adjustments are fairly simple and straightforward, there are a couple of recommendations that should be followed.

The XR-2207: Always adjust the lower frequency first with R_{1B} or R_{3B} and a low level on Pin 9. Then with a high level on Pin 9, adjust the high frequency using R_{2B} or R_{4B}. The second adjustment affects only the high-frequency, whereas the first adjustment affects both the low- and the high-frequencies.

The XR-2206: The upper and lower frequency adjustments are independent, and the sequence is not important.

The XR-2211: With the input open-circuited, the loop-phase detector output voltage is essentially undefined and VCO frequency may be anywhere within the lock range. There are several ways that f_o can be monitored:

1. Short Pin 2 to Pin 10 and measure f_o at Pin 3 with C_D disconnected;
2. Open R_5 and monitor Pin 13 or 14 with a high-impedance probe; or
3. Remove the resistor between Pin 7 and 8, and find the input frequency at which the FSK output changes state.

Note: Do NOT adjust the center frequency of the XR-2211 by monitoring the timing capacitor frequency with everything connected and no input signal applied.

For further information regarding the use of the XR-2207, XR-2206 and XR-2211 refer to the individual product data sheets.